Progress on the Development of a RF Driven D^- Ion Source for ITER NBI

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Introduction

- **Results from BATMAN in 2005**
  - Modified LAG Grid System
  - Parameter Dependencies
  - Experiments on Magnetic Confinement

- **Comments on Cs introduction**

- **Initial Hα – Beam Spectroscopy Results**

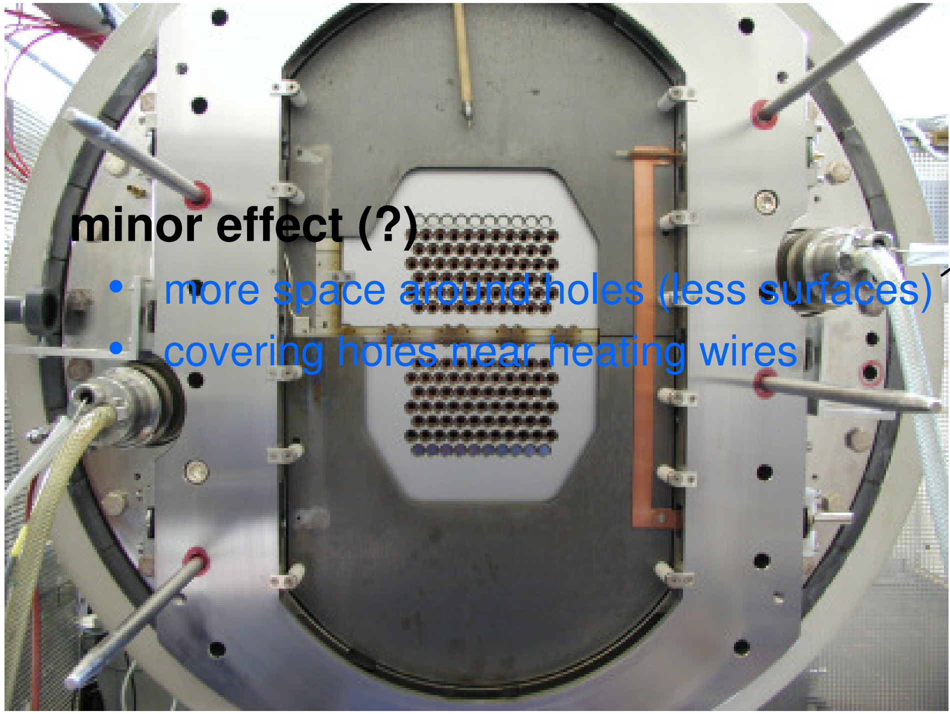
BATMAN Performance Compared to ITER Requirements

Parameter	ITER Requirement	BATMAN Hydrogen	BATMAN Deuterium
Current Density H	28 mA/cm^2	33 mA/cm^2	---
Current Density D	20 mA/cm^2	---	23 mA/cm^2
Electron - Ion Ratio	<1	0.36	0.9
Source Pressure	0.3 Pa	<0.3 Pa	<0.3 Pa
Extraction Voltage	9 kV	9.6 kV	9.9 kV
Pulse Length	3600 s	4 s	4 s
Extraction Area	2000 cm^2	70 cm^2	70 cm^2
RF Power	---	144 kW	125 kW
PG Temperature	---	197 C	222 C

The IPP NNBI RF source:

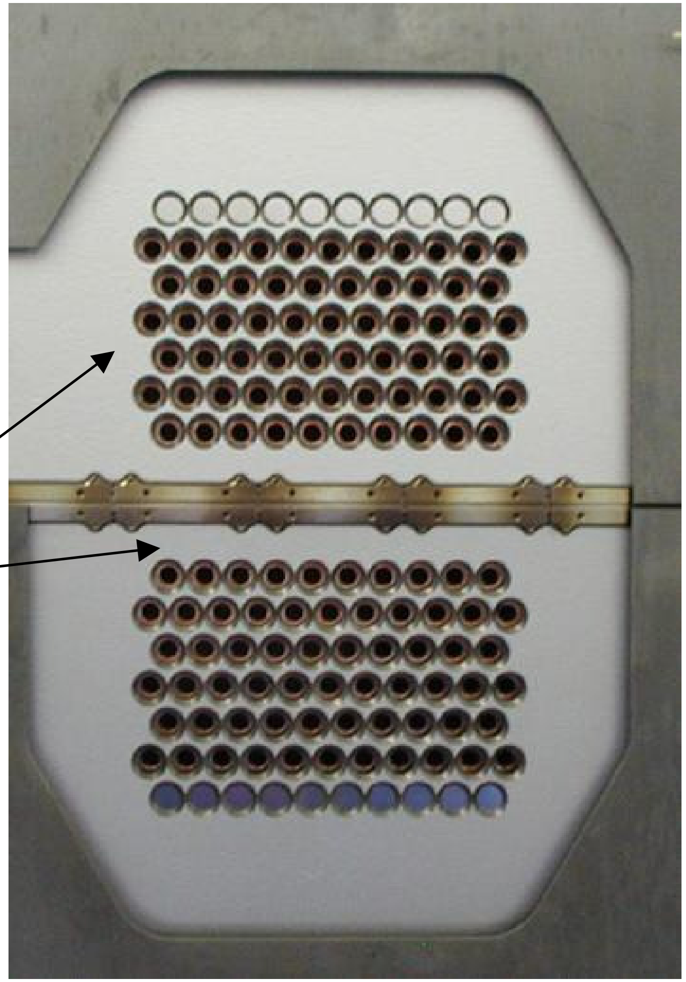
Improvement 2005:

- using a mask with chamfered holes in front of the plasma grid
    - high yield, high RF efficiency, similar for H and D
    - no dependence on grid temperature above 130 °C
      → water cooled grid possible



minor effect (?)

- more space around holes (less surfaces)
- covering holes near heating wires



The IPP NNBI RF source:
Low Pressure / Cs Operation

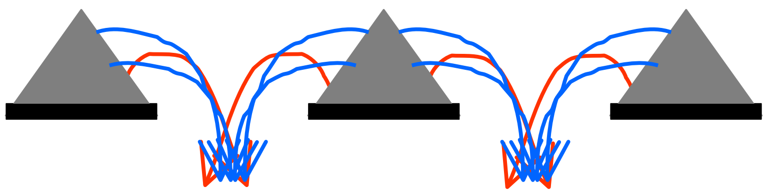
Physics of a cesiated RF source:

- H^- production at the plasma grid
  - needs Cs at the surface
  - mean free path some cm's

$$H^0, H^+ + \text{surface e} \rightarrow H^-$$

> few eV   >15 eV (RF)

- extraction of surface produced negative ions
  - problem of 'wrong' starting angle:
    ions produced at the grid are accelerated by the sheath potential back into the source and have to bend back towards the grid
    - ➔ bending mechanisms: CX, collisions, magnetic fields
    - ➔ bad beam quality



  - mask with chamfered holes
    - ➔ increases effective converter area in immediate vicinity of ex hole
    - ➔ increases solid angle for incoming H^0
    - ➔ improves „starting angles" of H^- leaving grid surface

The IPP NNBI RF source:
Low Pressure / Cs Operation: Daily Results

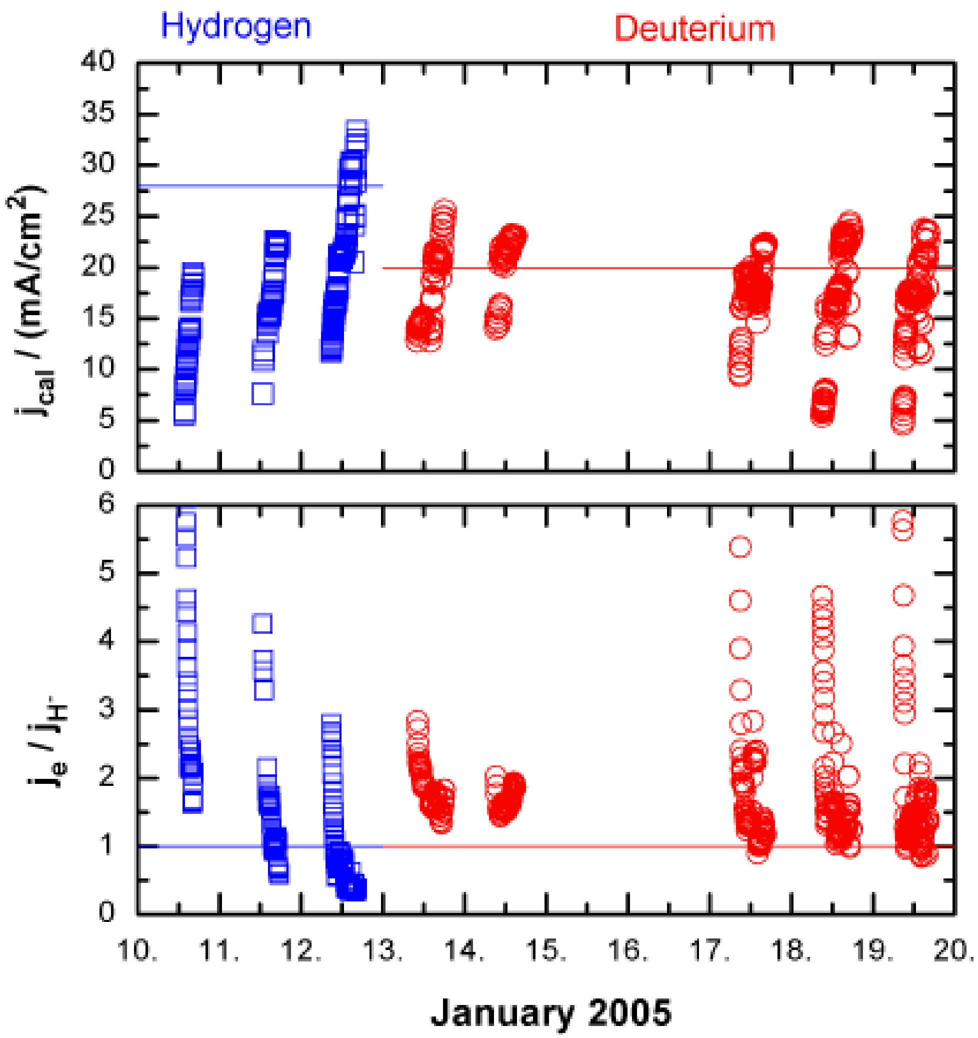
Results 2005:

- low pressure (0.2 – 0.5 Pa)
- extraction voltage up to 10.5 kV
- RF power < 130 kW
- 3 – 6 seconds

- cal. current density well above 28 mA/cm² (Hydrogen) / 20 mA/cm² (Deuterium) routinely achieved

- electron/ion ratio ≤ 1

- best results:
  33 mA/cm² H ($j_e/j_H = 0.5$)
  25 mA/cm² D ($j_e/j_D = 1.3$)
  23 mA/cm² D ($j_e/j_D = 0.9$)



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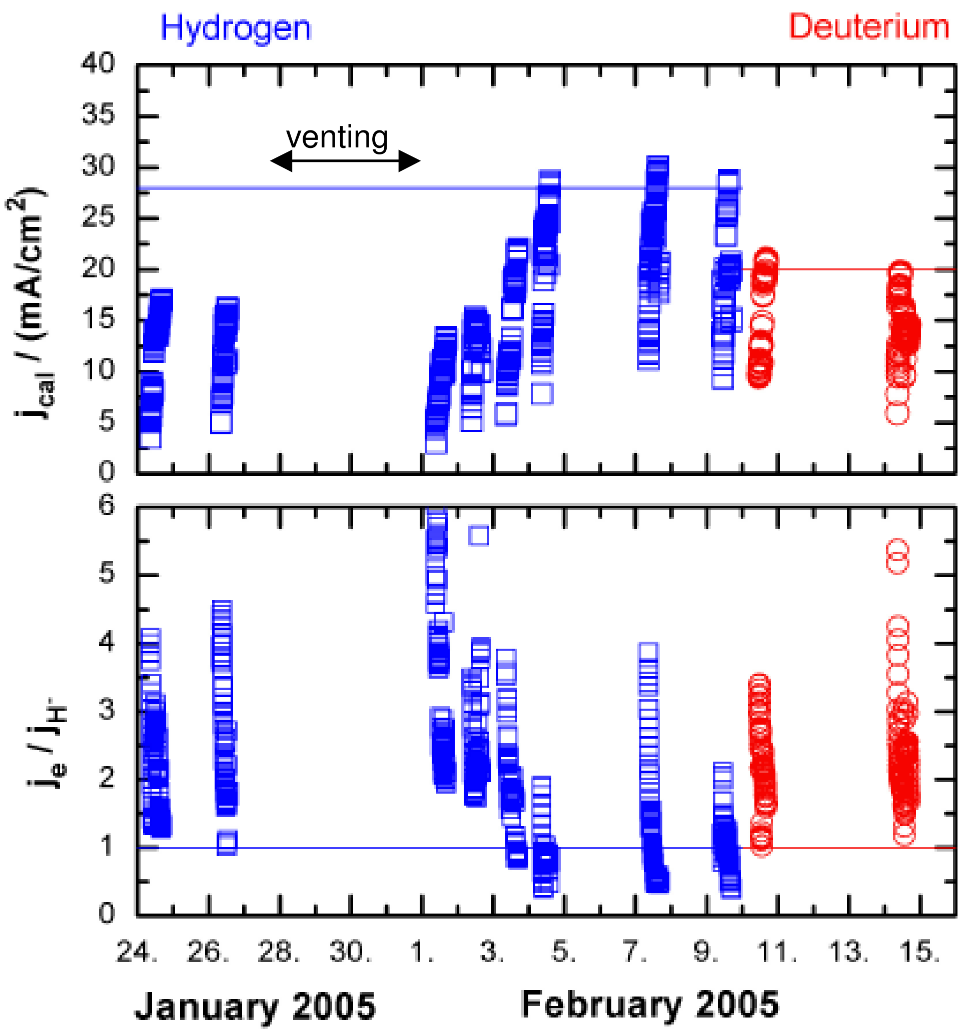
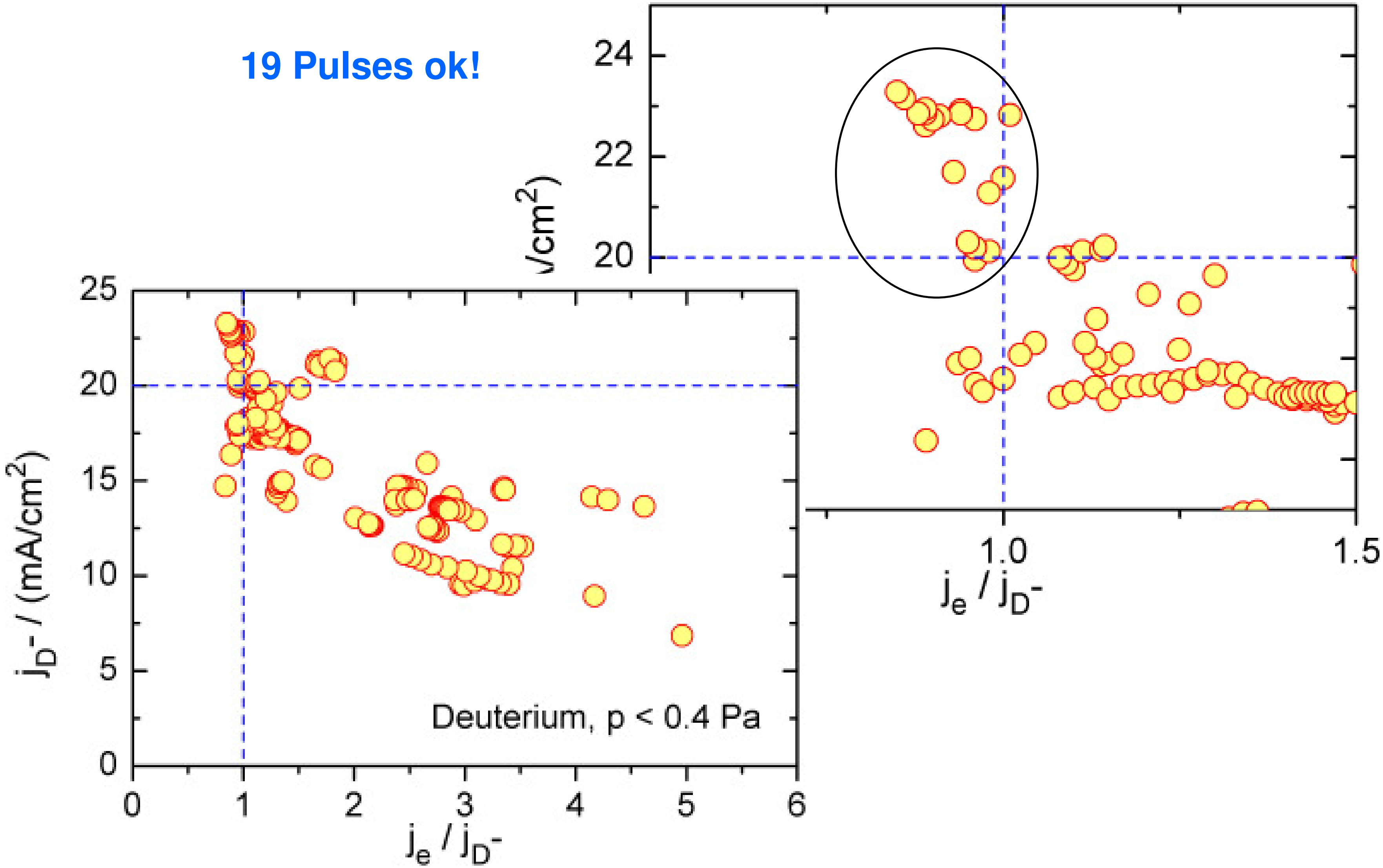
- 'fast' recovery after leak

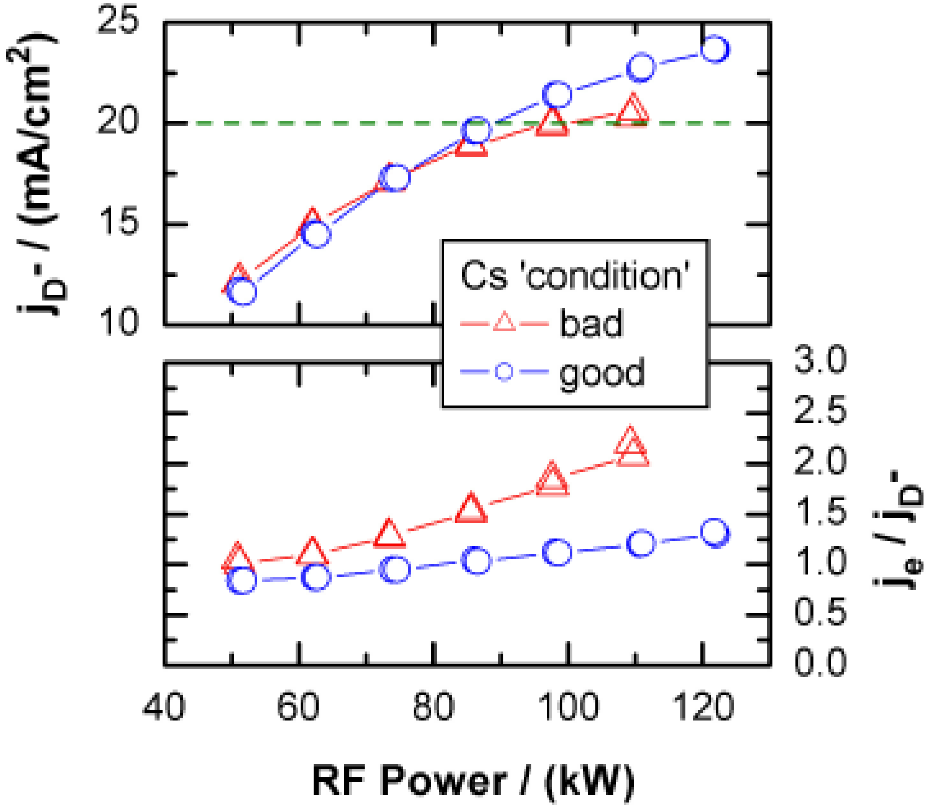


The IPP NNBI RF source: ITER Parameters

19 Pulses ok!



Low Pressure / Cs Operation: Parameter Dependence: RF Power



RF power:

- no saturation with RF power, if Cs distribution o.k.
- Deuterium, U_{ex} 9.5 kV, <0.5 Pa
- 'RF efficiency':

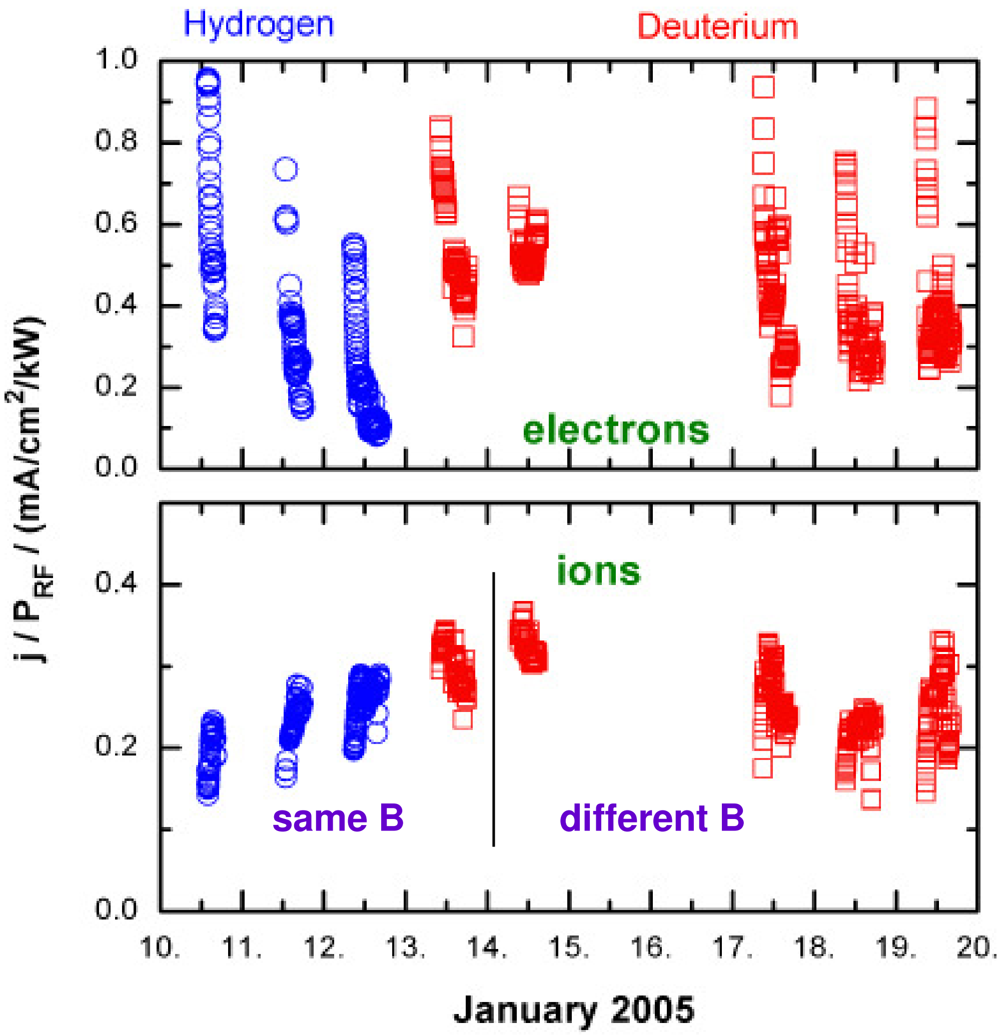
  j / P_{RF}

- reduces data scatter

The IPP NNBI RF source:
RF Efficiency

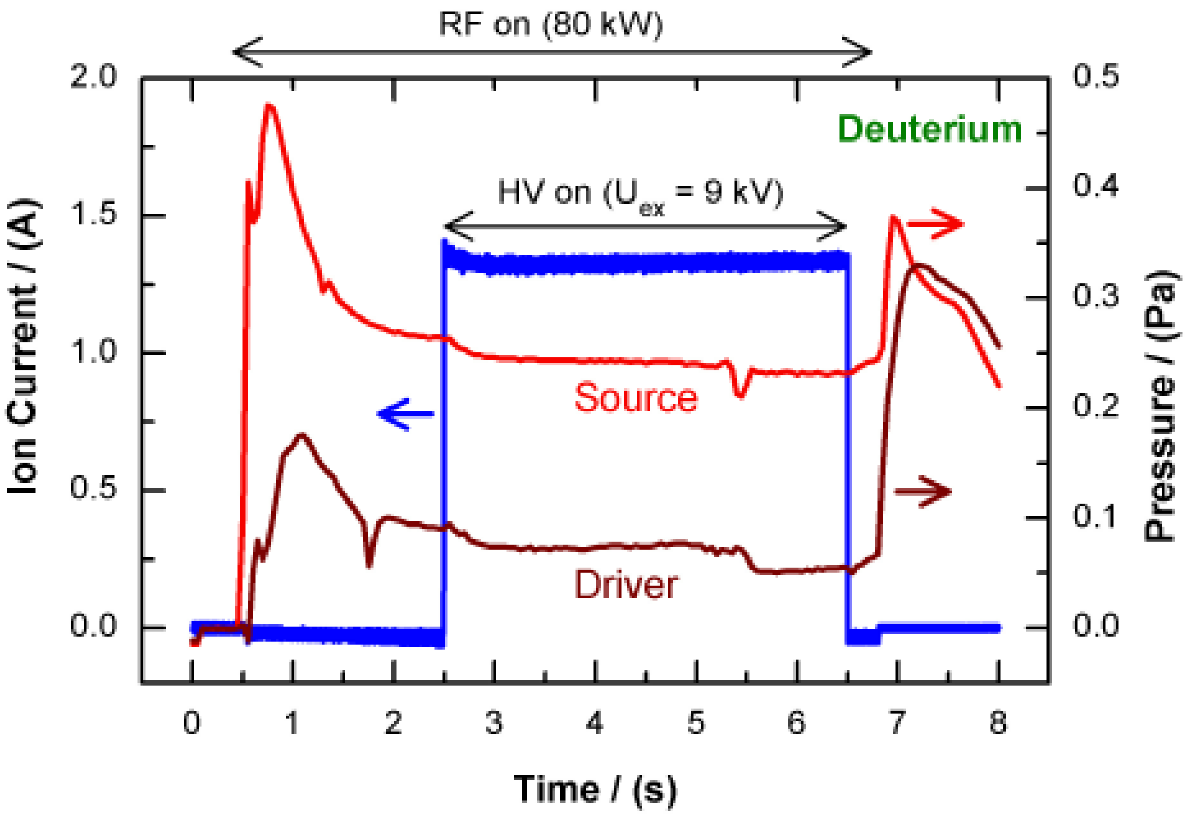
Results 2005:

- low pressure (0.2 – 0.5 Pa)
- extraction voltage up to 10.5 kV
- RF power < 130 kW
- RF efficiency ever higher for D
- differences due to different magnetic configuration of the ion source
- D needs more extraction voltage
- performance is limited by limitations in total / extraction voltage & in the power onto the extraction grid



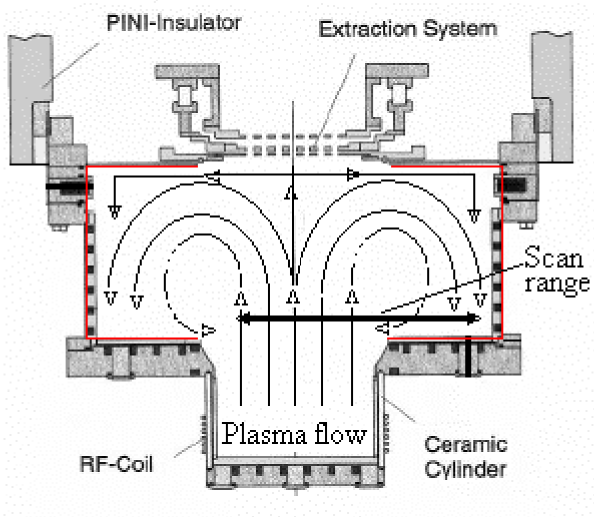
Low Pressure / Cs Operation:
Operation at low pressure

Low pressure operation: pressure drop in driver



18 mA/cm^2 onto cal.

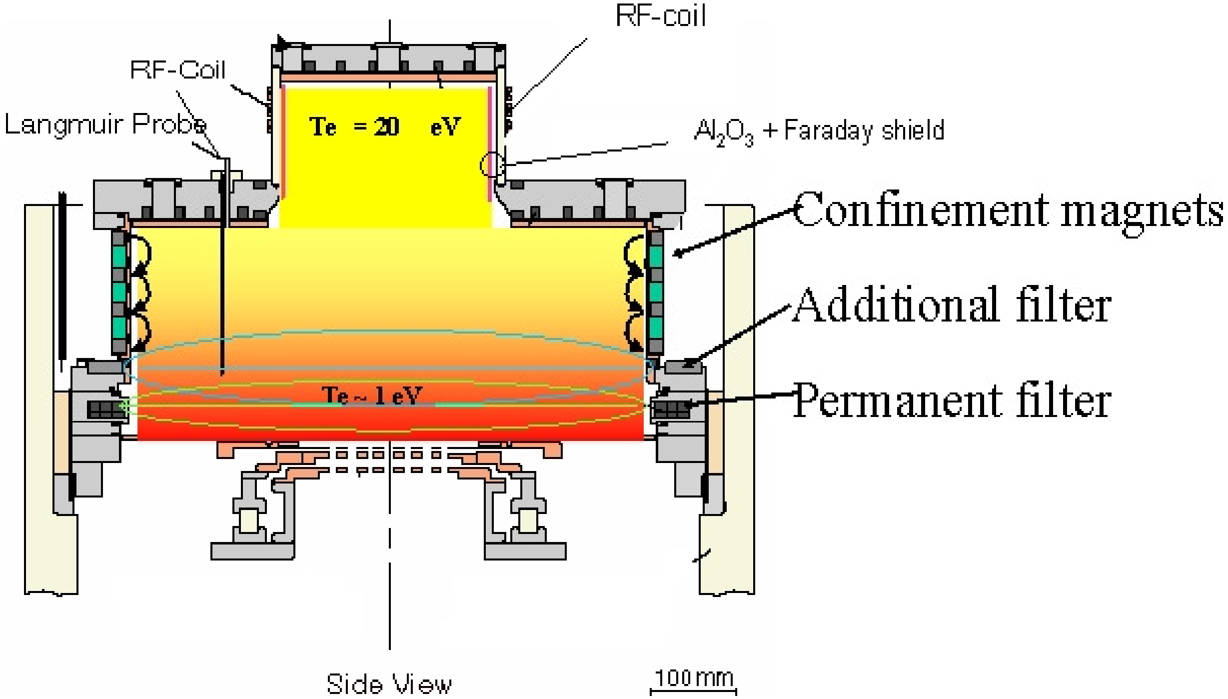
Filling pressure: 0.27 Pa



- RF coupling not efficient for high RF power when driver pressure is too low
- pressure drop increases with RF power, decreases with extraction area (larger gas flow)
  - better coupling at high RF powers for large sources → more current density !

IPP RF source:
Magnetic Confinement

- **flexible modification of filter field and side wall confining magnets**

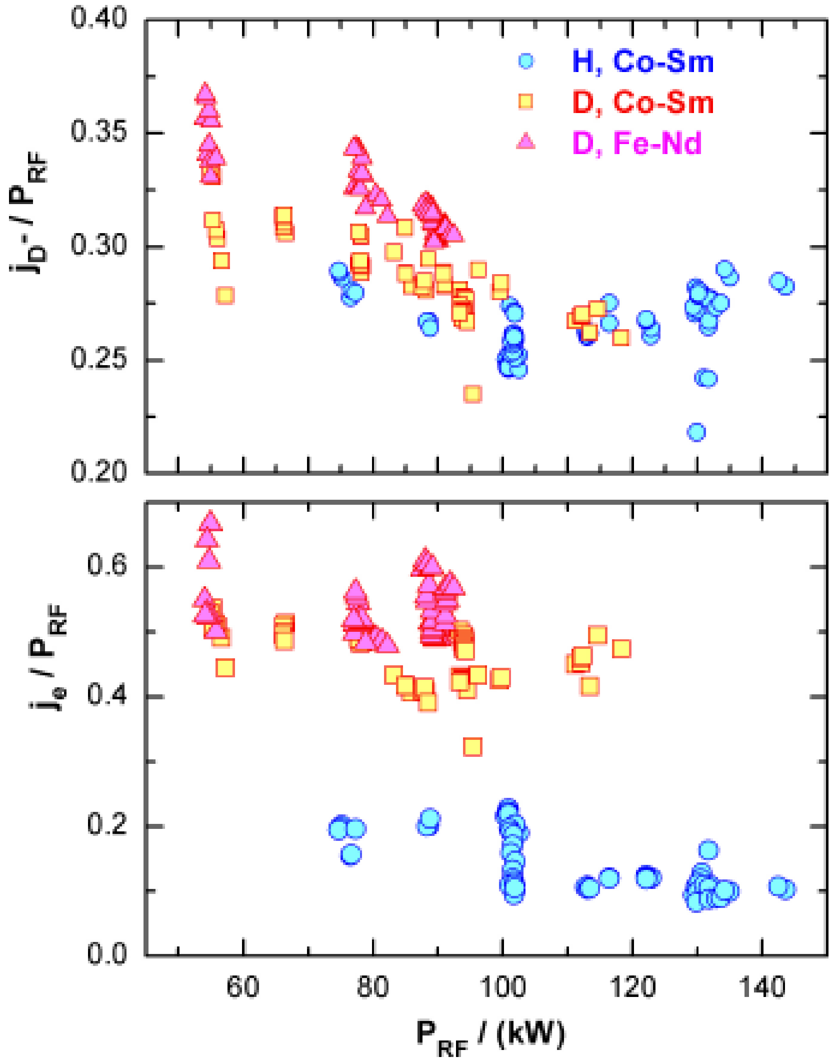


- side wall confining magnets influence filter field
- changing filter field effects plasma dynamics (→ Cs!)

IPP RF source:
Magnetic Confinement

General Behavior:

- Source can operate without side wall confining magnets (→j_{D^-} = 18 mA/cm²)
- Deuterium needs more filter field than hydrogen for electron suppression
  - up to now only possible with outside magnets
  - far-reaching field into the source
  - limits RF power coupling → reduces RF efficiency
- filter field has minor effect on source efficiency
- next experiments with more localized filter field (near grid)



The IPP NNBI RF source:
Cs Behaviour

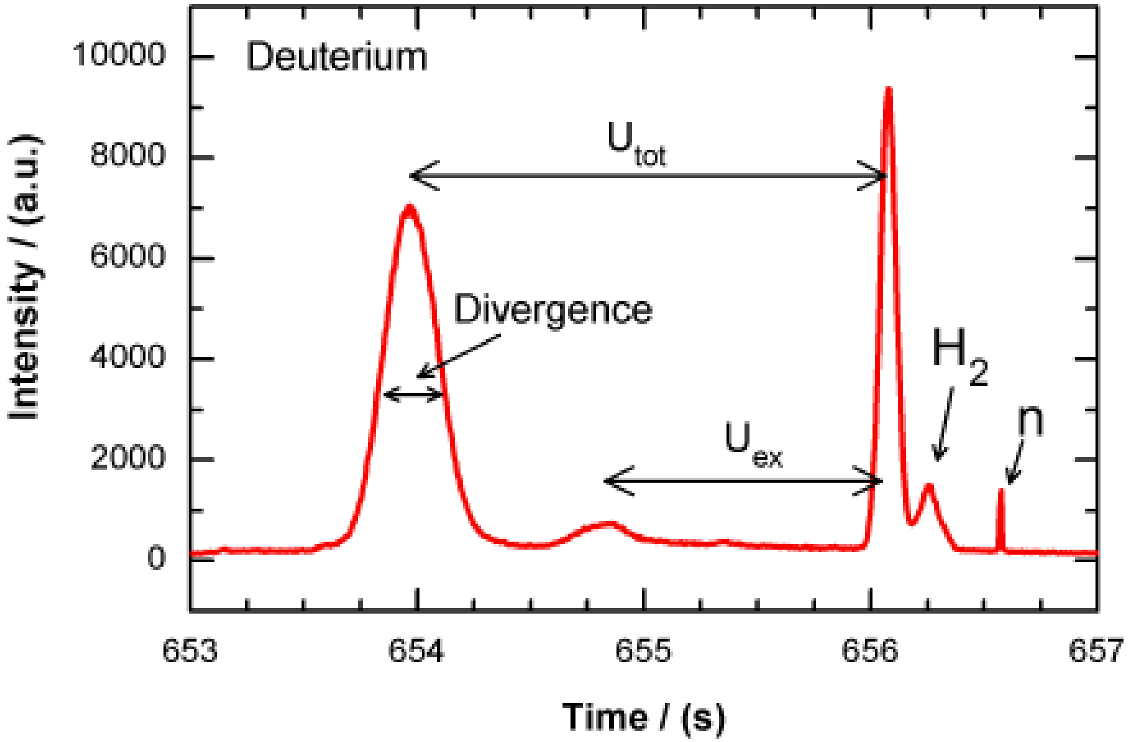
Improvement of RF source with Cs (2004/5):

- increase of current density by a factor 10
- hot plasma grid (~150 ºC)
- reduces amount of co-extracted electrons < 1
  (together with 10-15 V positive bias and sufficient filter field)

ITER requires reliable Cs seeded operation

- Cs seeded source subject to “De-conditioning”
- To achieve a properly conditioned Cs seeded source:
  - slow evaporation works best (10 mg/h)
  - look for signs that Cs on PG is “sufficient”:
    - ➔ electron current falls, ion current rises
- This requires Patience!
- diagnostic tools for more understanding (→ see talk of U. Fantz)

Hα Spectroscopy: Typical Spectrum



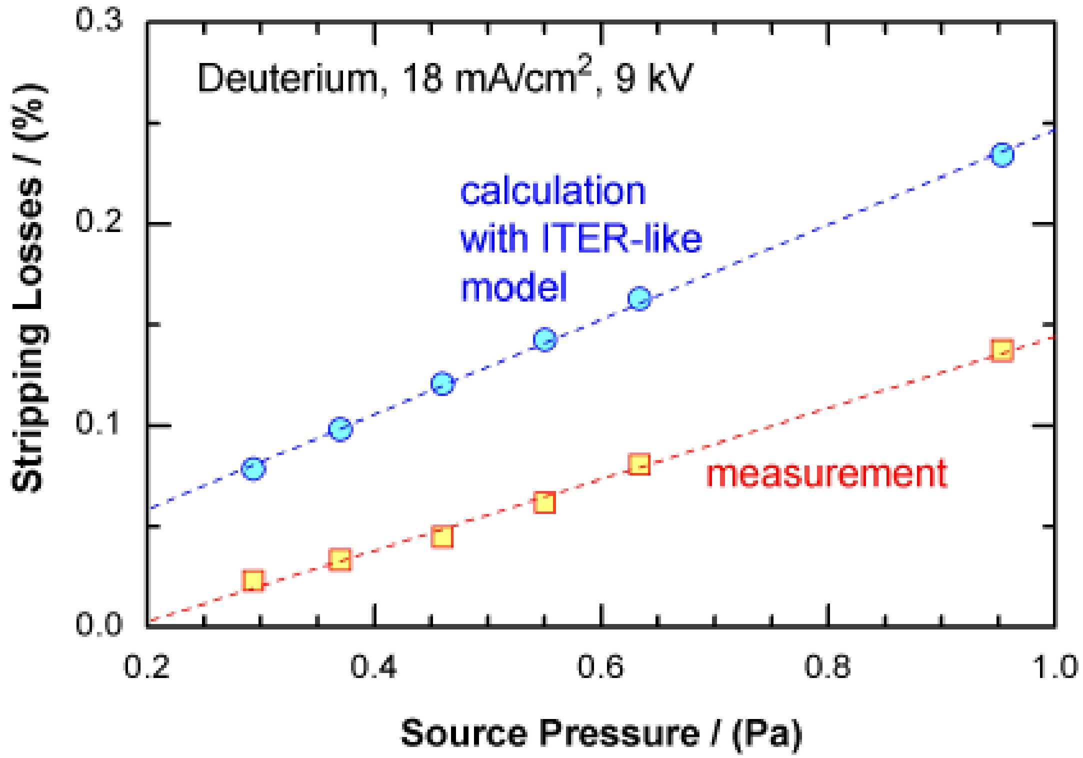
$$\Delta\lambda = \lambda_0 \cdot \frac{}{} \cdot \ldots \alpha \ldots (\ldots)$$

- measurement of stripped atoms leaving the accelerator
- depends on grid optics
- main stripping in first gap

Hα Spectroscopy: Stripping Losses

- low stripping:
  $j_{cal} = j_{extracted}$
  (assume all D- have full energy)

- Calculation:
  - only conductance of grids
  - gas temperature of 300 K
  - but source: 1000 – 1200 K



- same model as used in ITER stripping loss calculations
  - ITER calculations may be too pessimistic ?
    → modelling with trajectories for stripping losses in the grid necessary

Summary

- **exceed all ITER objectives except pulse length simultaneously on BATMAN**
  - >22 mA/cm^2 in deuterium, >30 mA/cm^2 in hydrogen at $I_{elec}/I_{ion} < 1$ and at pressures below 0.3 Pa in driver and filling pressure
  - reliable and reproducible operation over 3 months
  - even higher source efficiency for deuterium
  - stronger filter required for Deuterium: modifications under way
  - wall confinement affects source efficiency

- **deuterium operation is limited by**
  - power on extraction grid due to higher electron ion / ratio
  - RF coupling at low pressures due to pressure drop in driver and far-reaching filter fields

larger sources and modified filter fields:

→ increase in RF power possible

→ expect same current densities for Deuterium as for hydrogen!

BATMAN (Current Accountability)

- **Electrical Currents are all measured:**
  - I_{ion} gives J_{ion} *(elec)*
  - I_{elec}
  - I_{GG} gives J_{ion} *(GG)*

Shot 24387
I_{drain} = 4.54 A
I_{elec} = 2.15 A
I_{ion} = 1.98 A (26.64 mAcm^{-2})
I_{GG} = 0.33 A (4.39 mAcm^{-2})
J_{H-} (TC) = 20.5 mAcm^{-2}

- **Calorimeter signals give J_{ion} *(TC)* and J_{ion} *(W)***

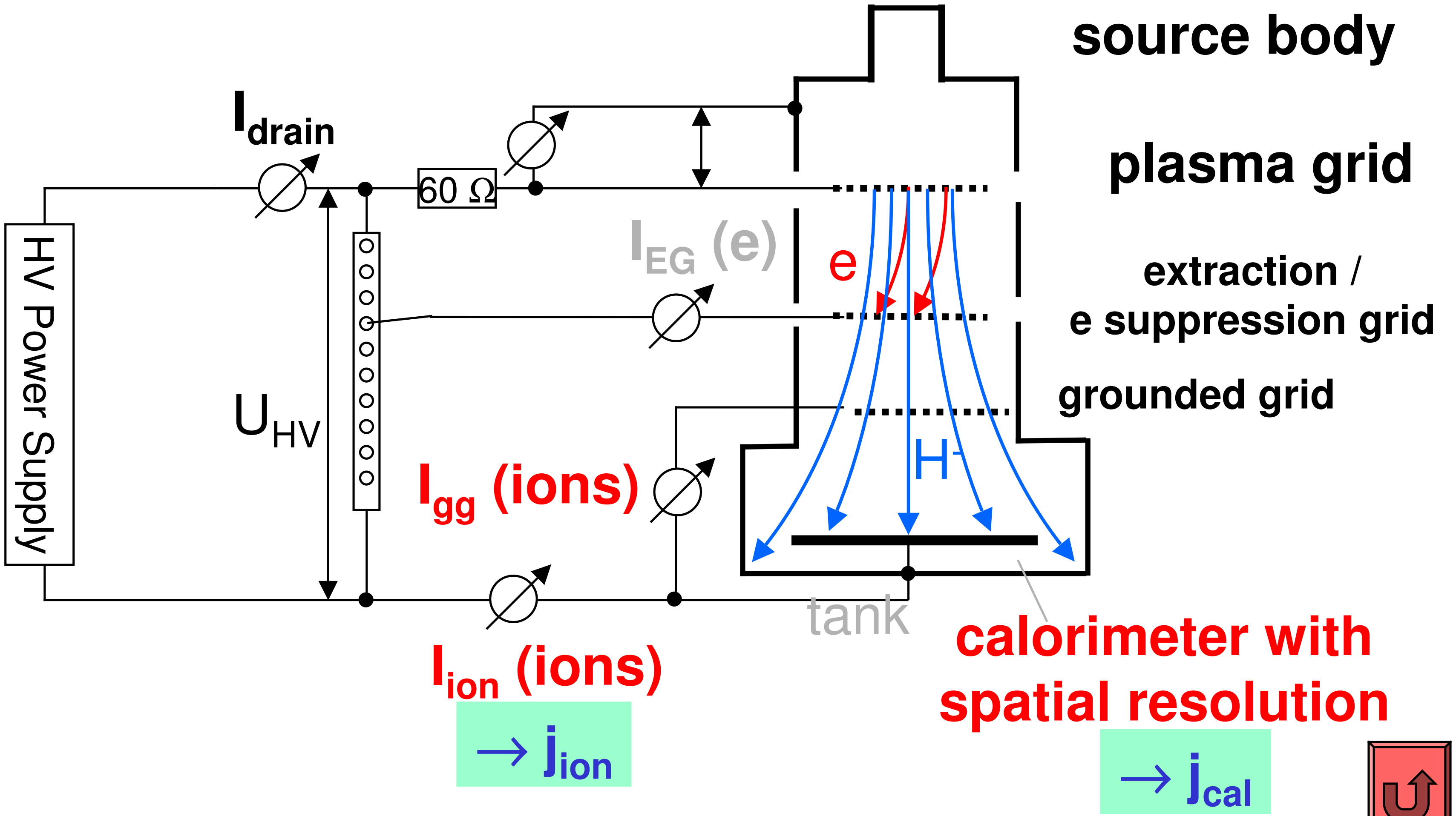
- **J_{ion} *(TC)* and J_{ion} *(W)* are systematically different**
  - Likely the flow meter is slightly off

- **Accountability: J_{ion} *(TC)* to J_{ion}*(elec)* ≈ 90%.**

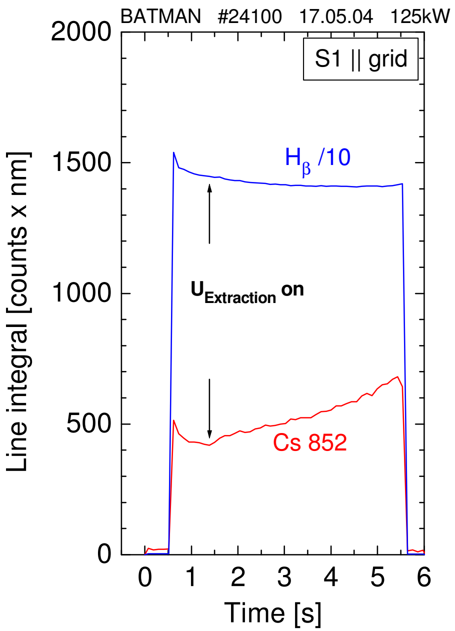
Accounting

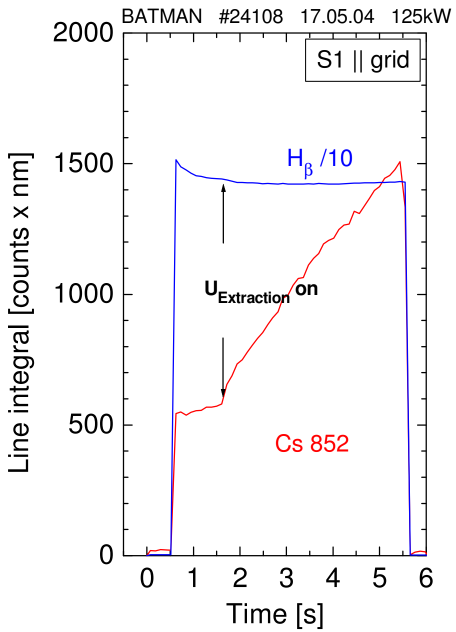
Layout

Beam extraction: BATMAN



Spectroscopy on the Cs 852 nm Line

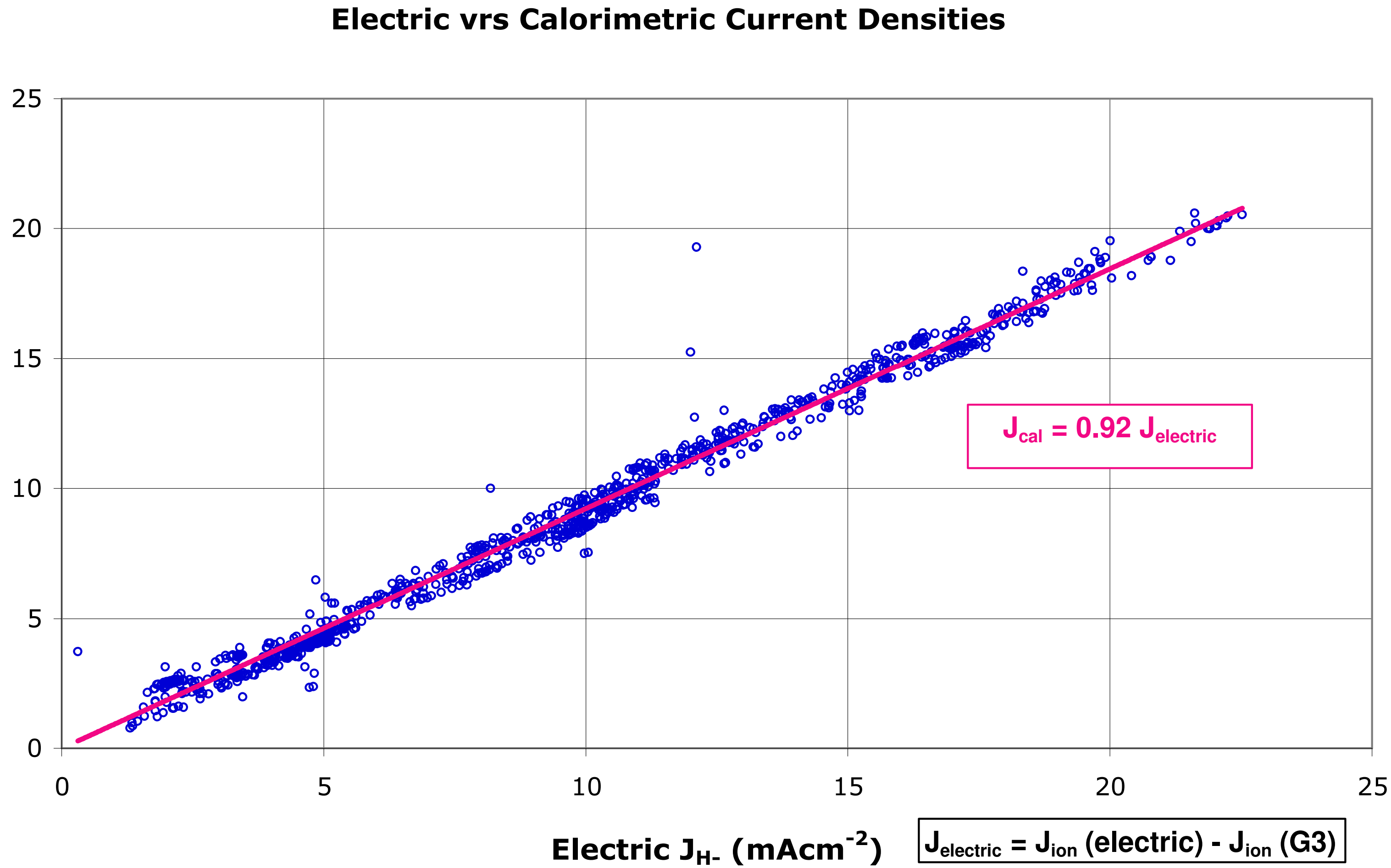




Before start of first Cs evaporation after source modifications

After start of Cs evaporation (4 mgr evaporated)

BATMAN (LAG)



Electric vrs Calorimetric Current Densities
25
20
15
10
5
0
0
5
10
15
20
25
J_{cal} = 0.92 $J_{electric}$
Electric J_{H-} ($mAcm^{-2}$)
$J_{electric}$ = J_{ion} (electric) - J_{ion} (G3)